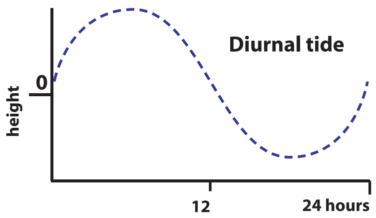
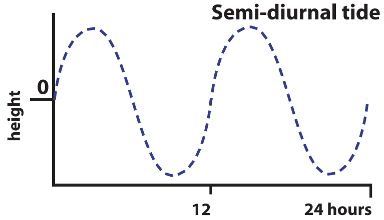
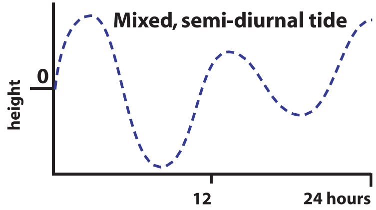




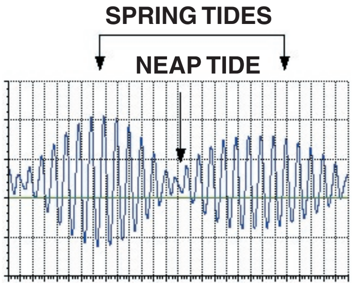


Tide Patterns

In a few coastal areas, there is a pattern of one high tide and one low tide per day. This tidal pattern is called a diurnal tide.

The dominant tidal pattern in most of the world's oceans is two tidal cycles where the high water-low water sequence occurs twice a day. If the highs and lows in a semi-diurnal tide occur at different levels, the tide is referred to as a mixed, semi-diurnal tide.

The predicted astronomical tidal pattern is often modified by other factors. Winds acting on the sea surface and atmospheric pressure can modify the sea level. These types of events can be particularly important in shallow-water areas. Strong coastal storms can markedly modify the tidal patterns for a particular area.

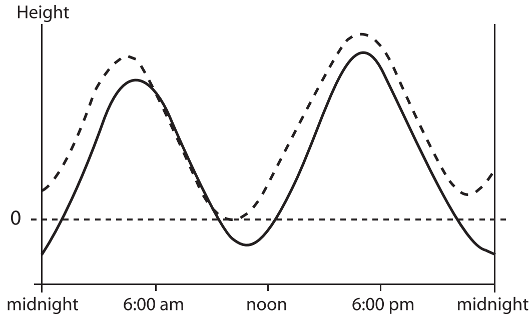


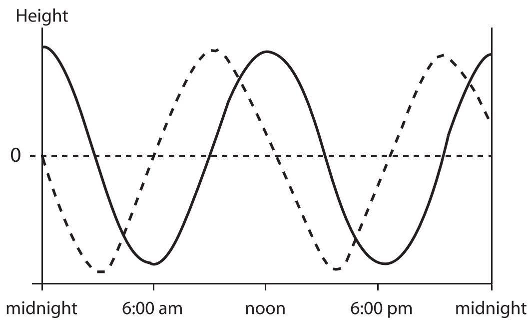
Spring and Neap Tides

Spring tide is the very highest and very lowest tide, which occurs twice a month when the moon is either new or full.

Neap tides are the opposite of the spring tide: the tidal range between high and low water is smallest and occurs near the time of the first and last lunar quarters.

Spring tides may be important for spill response as oil beached during this time is likely to remain stranded on the upper portion of the shoreline until the next spring tide (about 14 days) or storm event. If there is a storm surge during a spring tide, the oil can remain stranded for a much longer period.





Tidal Currents

Strongest tidal currents are found in shallow-water areas or through narrow channels that connect large bodies of water.

Currents in channels (i.e., entrances to bays and estuaries) are constrained to flow either up or down the channel. In open waters, the flow depends on the direction of the tide wave.

Along the outer coasts, the tidal currents and heights are more closely in phase (progressive wave).

Tidal currents are generally out of phase with tide heights for stations inside an enclosed bay (standing wave). Phase change can also be caused by bottom friction.

Tidal currents and heights at the entrance to Galveston Bay. Solid line is tidal heights and the dashed line is tidal currents. (top)

Tidal currents and heights at the entrance to Portland Harbor, Casco Bay, Maine. Solid line is tidal heights and the dashed line is tidal currents. Note max flood is about 3 hours earlier than high tide. (bottom)

$$\text{Tidal excursion} = V\frac{T}{\pi}$$

To calculate the tidal excursion, let

T = Time from low slack to low slack (high slack to high slack)

V = Maximum tidal current velocity

Tidal Excursion

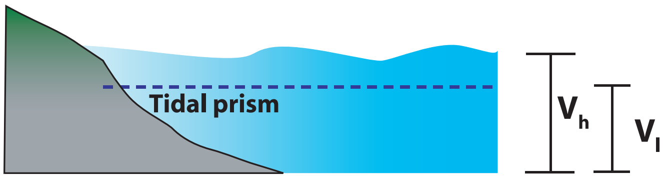
The trajectory analyst is often asked whether an offshore spill will move into a bay or estuary. To answer this question, one of the first things you should look at is the tidal excursion for the inlet. If the spill is anywhere near the extent of the tidal excursion, oil could move into the bay with the tide.

It is important to keep in mind that the tidal excursion is very much dependent on the bathymetry. In areas where the bottom is very broad and flat, the tidal influence will drop off quickly. In long, narrow channels, the tidal influence could be much larger.

Flushing

The volume of water exchanged between an estuary and the open sea during a complete tidal cycle is often called the tidal prism. In the figure, the difference between the volume of water at low tide (below the dashed line) and high tide (below the curved line) is the tidal prism.

The tidal prism method for estimating flushing assumes that the water entering on the flood tide is fully mixed with the water inside the estuary. It also assumes that the volume of river water and sea water during the flood tide equals the tidal prism.



Vertical profile of a simplified shoreline. Area between the curving and dashed lines indicates the tidal prism.

To calculate the flushing time, first measure the area of the estuary from a map. Second, calculate the volume of the estuary at low water, by selecting a depth that best represents the estuary. Third, calculate the volume of the estuary at high water, V_h. Finally, the flush time can be calculated from $f_t = \left(\frac{V_h}{V_h - V_l} \right) t_c$

where t_c is the time of one tide cycle (from low tide to low tide) and V_l is the volume of water in the estuary at low tide

This is a general approach, but the method may underestimate flushing time due to incomplete mixing; fresh water at the head of the estuary may not move through the mouth of the estuary in one tide cycle and some water that escaped on the ebb is returned on the flood. Underestimating flushing times may mean that the oil remains in the estuary longer than predicted.

***Exxon Valdez* oil spill**

Turbulent Mixing

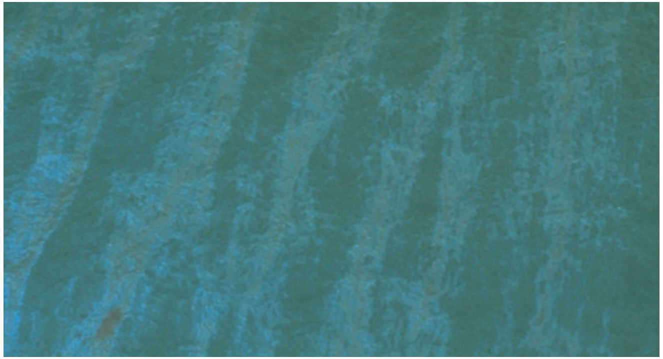
Oil spilled into water is subjected to turbulent flow. Oceanic turbulence is generated by winds and current, and by heating and cooling. Flow in the upper layers of water becomes more turbulent as the wind and current increases.

Turbulent diffusion, caused by random bulk movements of water, tears oil slicks into smaller patches that are distributed over a wider area.

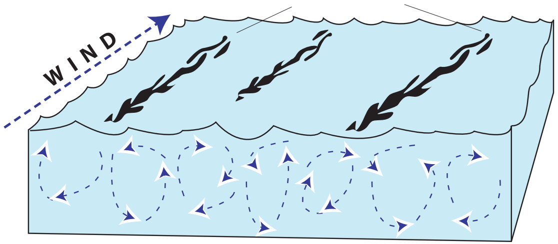
The diffusion of oil occurs mainly in the horizontal direction. Horizontal diffusion of the surface water ranges from 100 to 1,000,000 cm^2/s.

Diffusion in the vertical direction is much smaller by orders of magnitude than horizontal diffusion and generally decreases with depth.

Turbulent diffusion is not to be confused with mechanical dispersion (i.e., mixing caused by breaking waves).



Oil in widrows, or Langmuir cells.



Langmuir cells in the mixed layer depth.

Langmuir Circulation

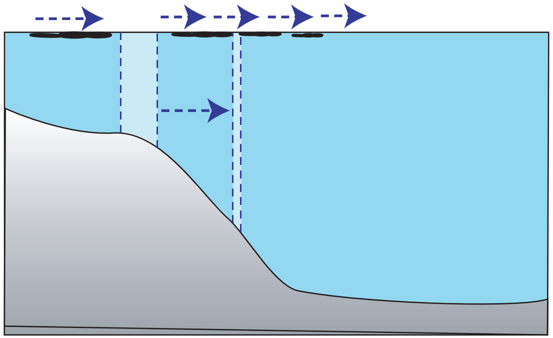
Langmuir circulation is the result of the interaction between wind-driven surface currents and surface waves. Though Langmuir circulation may be present in weak or no-wind situations, it is most often seen when the wind speed is 1.5 m/s or greater. Langmuir circulation is a major mechanism for breaking the slick up and may be important for transporting oil droplets into the water column. Predicting the onset and strength is difficult at best, but we do know the following:

1) The windrows, or streaks, tend to last from 5 to 30 minutes, then dissipate and reform.

2) The surface current, stronger in windrows, can be up to 5.5% of the wind speed.

3) Downwelling (vertical) speeds at convergence range from 5 cm/s to 20 cm/s.

Reference: Special Issue Langmuir Circulation and Oil Spill Modeling. *Spill Science and Technology Bulletin Vol. 6*



Water column moves from shallow water to deeper water.

Tidal Convergences

Convergences are natural collection areas for oil, especially tarballs. Because they are close together, the tarballs in a convergence may coalesce and form a cohesive slick.

Tidal convergences can be formed by water moving from shallow to deeper water (ebb tide) that is stretched. To conserve mass, the surface velocity decreases.

Flotsam, rafting birds, and oil can collect in these areas.

Under weak winds, the oil may not cross convergences. Strong winds may rupture the convergence. However, tidal convergence can appear consistently in the same general area during ebb tides.

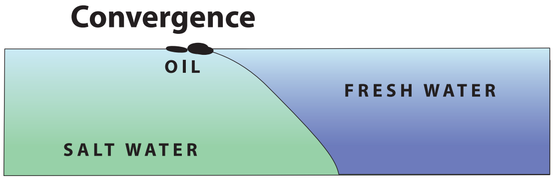
Freshwater-saltwater Interface

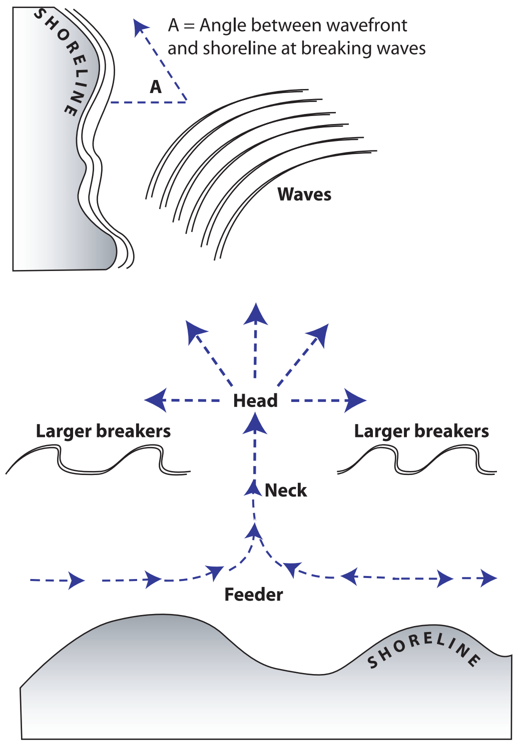
As with tidal convergences, the freshwater-saltwater interface is also a natural collection area for oil. However, this type of convergence is formed by river water flowing into the sea and spreading out over the seawater.

The fresh water is less dense than the seawater, creating a convergence at the surface.

Strong winds can rupture these convergences.

Freshwater-saltwater interface with oil sheen moving into the convergence.





Formation of longshore currents

Longshore Currents

Longshore currents are produced by waves approaching, at an oblique angle, a coastline having a gently sloping beach.

Speed and direction of the longshore current increase with wave height and with an increase in the angle of the wave front.

Typical speeds of longshore currents range from 0.3 m/s to 1.0 m/s.

As the current approaches 1.5 m/s, a jet often forms that returns flow seaward in the form of rip currents.

This type of current is very important for trajectory purposes as it provides a mechanism for transporting oil in nearshore areas beyond the breakers and offshore.

Reference: Horikawa, K. 1978. *An Introduction to Coastal Engineering*. New York: John Wiley and Sons. 403pp.

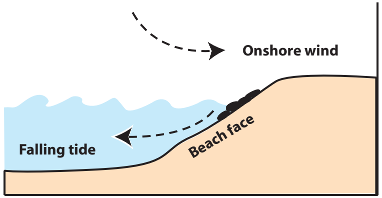
Beaching/Refloating

Ocean currents cannot actually bring the oil into contact with the shoreline unless there is some kind of flow that penetrates the shoreline (e.g., marshes and mangroves). The first photograph shows an oil spill moving into a marsh on a flood tide.

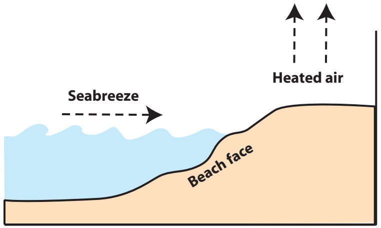
The second photograph shows streaks of oil moving along the shoreline. For the oil to beach, the wind must typically be blowing onshore.

Oil in marsh.

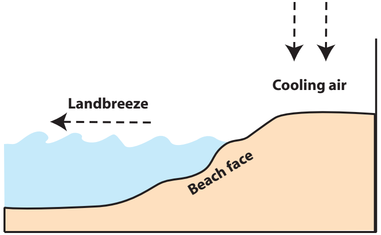
Oil streaks moving parallel to the shoreline.



Oil beaching with a falling tide and onshore wind.



Heating of the land and a sea breeze (from sea to land) during the day.



Cooling of the land and a land breeze (from land to sea) during the night.

Land/Sea Breeze

A falling tide with an onshore wind greatly increases the amount of shoreline oiling (see first figure). A sea breeze may strand the oil on the shore.

The land and sea breeze cycle occurs in many coastal areas and is caused by heating of the land during the day and cooling at night (see second and third figures). In some areas, the land and sea breeze can extend many miles off-shore.